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ON RADIO QUIESCENCE OF ANOMALOUS X-RAY PULSARS AND SOFT GAMMA-RAY REPEATERS

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ABSTRACT

In the hot environments of the anomalous X-ray pulsars and the soft gamma-ray repeaters, as indicated by their luminous, pulsed, quiescent X-ray emission, γ-rays generated from the inner gaps may have shorter attenuation lengths via two photon pair production than via magnetic photon splitting. The AXP/SGR environments may not be pairless, even if photon splitting could completely suppress one photon pair production in super-strong magnetic fields, as conjectured by Baring & Harding. Two-photon pair production more likely occurs near the threshold, which tends to generate low energy pairs that are not energetic enough to power radio emission in the observed bands. However, emission in longer wavelengths may not be prohibited in principle if these objects are indeed magnetars. The so-called "photon splitting deathlines" are still valid for high magnetic field pulsars which are much dimmer in X-rays, if γ-rays with both polarization modes split.

Subject headings: gamma rays: theory - magnetic fields - pulsars: general - radiation mechanisms: general - stars: neutron

1. INTRODUCTION

There is now growing evidence that the anomalous X-ray pulsars (AXPs) and the soft gamma-ray repeaters (SGRs) are isolated neutron stars which form a distinct group with respect to the conventional rotation-powered radio pulsars. In the quiescent state, AXPs/SGRs differ from normal pulsars by showing the following peculiar characteristics: (1) long periods, P, and high spindown rates, $\dot{P}$; (2) much more luminous pulsed X-ray emission with $L_x \sim 10^{35} - 10^{36}$ erg s^{-1}; (3) no firmly detected radio emission. A popular model for these objects is the magnetar model (e.g. Duncan & Thompson 1992), which involves strongly-magnetized neutron stars with dipolar magnetic field strengths at the surfaces of order $B_p \sim 10^{14} - 10^{16}$. The magnetic braking naturally interprets the timing data of AXPs/SGRs (e.g. Kouveliotou et al. 1998). The luminous pulsed X-ray emission may be explained as decay of super-strong magnetic fields (Thompson & Duncan 1996). Radio quiescence of magnetars has been attributed to the possible function of an exotic QED process, magnetic photon splitting, which may strongly suppress one-photon pair production in magnetic fields above roughly the critical value, $B_q = m_e^2 c^3/e\hbar \simeq 4.4 \times 10^{13}$ G (Baring & Harding 1998; 2001). The relative orientation between the magnetic and the rotational axes may be also essential to judge whether a delayed pair formation front might form, and hence, whether a high magnetic field pulsar (HBP) or a magnetar is radio quiet (Zhang & Harding 2000). Here we will show through a rough estimation that, in the hot magnetar environments as inferred from the observations, a previously un-explored effect, i.e., two photon pair production, may not be completely suppressed by magnetic photon splitting, even if the latter can completely suppress one photon pair production. The AXP/SGR environments therefore may not be necessarily pairless. We discuss the possible implications of such a process in understanding the AXP/SGR/HBP phenomenology.

2. ONE-PHOTON PAIR PRODUCTION, MAGNETIC PHOTON SPLITTING, AND TWO-PHOTON PAIR PRODUCTION

An isolated rotating neutron star is a unipolar generator, which generates a large potential drop between the magnetic pole and the polar cap edge, i.e., $\Phi \sim B_p R^3 \Omega^2/2c^2 \sim 6.6 \times 10^{12}$ V$B_{p,14} P_1^{-2} R_6^3$, where B_p, Ω, P and R are the polar cap surface magnetic field strength, the rotational frequency, the period, and the radius of the neutron star, respectively. Here the parameters are normalized to a typical magnetar, and the convention $Q = 10^n Q_n$ has been used. The maximum achievable electron energy is $\gamma_{p,m} \sim e\Phi/m_e c^2 \sim 1.3 \times 10^7 B_{p,14} P_1^{-2} R_6^3$. In reality, such a high energy may be not achievable due to screening of the parallel electric fields by pairs, or due to radiation self-reaction of the electrons. The typical primary particle energy, γ_p, is model-dependent (e.g. Zhang, Harding & Muslimov 2000, for normal field pulsars).

One-photon pair production (also called $\gamma - B$ process), i.e., $\gamma \rightarrow e^+e^-$, is a first order QED process which only operates in the presence of a strong magnetic field. It is commonly accepted to be the main source of pairs in pulsar magnetospheres, and the conditions for this process to cease (e.g. Zhang et al. 2000) or to be suppressed (e.g. Baring & Harding 1998; 2001) conventionally define the so-called radio emission "deathlines" of pulsars. In the high magnetic field regime which we are interested in, one photon pair production occurs as soon as the threshold condition, $\epsilon \sin\theta = 2$, is fulfilled, where ϵ is the γ-ray energy in units of the electron's rest mass, $m_e c^2$, $\theta \sim l/\rho + \vec{\theta}_0$ is the angle between the photon momentum and the local magnetic field. Here we denote l as the distance the photon would travel if the initial injection angle is zero, ρ as the field line curvature, so that the angle l/ρ defines the electron's moving direction at the emitting point, which we call the propagation direction. The vector $\vec{\theta}_0$ is the initial photon ejection pitch angle with respect to the electron's moving direction which should be added to the l/ρ term

according to the vector algebra. The angle $\theta_0 = |\vec{\theta}_0|$ depends on the mechanism that generates the photon, e.g., $\theta_0 \sim \gamma_p^{-1}$ for inverse Compton, and $\theta_0 \sim 0$ for curvature radiation. When $\theta_0 \sim 0$, the impact angle θ is solely determined by the propagation effect, and the one-photon pair production attenuation length can be approximated as

$$\lambda_{1p}(\epsilon) = 2\rho\epsilon^{-1} \simeq 1.84 \times 10^8 \text{ cm } \epsilon^{-1} P^{1/2} r_{e,6}^{1/2} \xi^{-1}, \quad (1)$$

where a dipolar geometry, $\rho = 9.2 \times 10^7$ cm $r_{e,6}^{1/2} P^{1/2} \xi^{-1}$, is assumed throughout the paper, r_e is the radius at which the γ-ray is emitted, and $0 < \xi = \Theta_s/\Theta_{\rm pc} < 1$ is the ratio of the field line magnetic colatitude at the surface to the polar cap angle. For $\theta_0 \sim \gamma_p^{-1}$, the in-situ one-photon threshold energy is $\epsilon_{th,1p} \sim 2/\theta_0 \sim 2\gamma_p \sim 2 \times 10^5 \gamma_{p,5}$, photons with energies above which have a pair-production attenuation length $\lambda_{1p}(\epsilon > \epsilon_{th,1p}) \sim 0$. Far below this in-situ threshold, $\epsilon \ll 2 \times 10^5 \gamma_{p,5}$, photons usually propagate until $l/\rho \gg \theta_0$ and the attenuation length is essentially defined by (1). For photons with $\epsilon \lesssim 2 \times 10^5 \gamma_{p,5}$, the superposition between the two direction vectors is important, and the θ_0 effect can either decrease *or increase* the attenuation length depending on whether the photon ejection direction is on the convex or concave side of the field line.

Magnetic photon splitting, i.e., $\gamma \to \gamma\gamma$, is a more exotic, third order QED process which only becomes prominent when the field strength is above B_q. Under the weak linear vacuum dispersion limit, only one splitting mode, i.e., $\perp \to \parallel\parallel$, can fulfill the energy and momentum conservation requirements simultaneously (Adler 1971). However, Baring & Harding (1998; 2001) argued that in the special environment of a magnetar, strong vacuum dispersion may arise, so that it is possible that all the three photon splitting modes permitted by charge-parity invariance in QED, i.e., $\perp \to \parallel\parallel$, $\perp \to \perp\perp$, and $\parallel \to \perp \parallel$, may operate together. If this is indeed the case, photons with both polarization modes split, and a splitting cascade will occur in a magnetar inner magnetosphere until all the hard photons split to soft ones below the one-photon pair production threshold. The magnetar magnetosphere is therefore essentially pairless, which may offer a natural explanation for radio quiescence of the known AXPs/SGRs. In the low-energy non-dispersive limit, the polarization-averaged photon splitting attenuation coefficient is (Harding, Baring & Gonthier 1997)

$$\begin{aligned} T_{sp}(\epsilon) &\approx \frac{\alpha^3}{10\pi^2} \frac{1}{\Lambda} \left(\frac{19}{315}\right)^2 \mathcal{F}(B') B'^6 \epsilon^5 \sin^6\theta \\ &\simeq 0.37 \mathcal{F}(B') B'^6 \epsilon^5 \sin^6\theta, \end{aligned} \quad (2)$$

where α is the fine-structure constant, $\Lambda = \hbar/(m_e c) \simeq 3.86 \times 10^{-11}$ cm is the Compton wavelength of the electron, $B' = B/B_q$, and $\mathcal{F}(B')$ is a strong-field modification factor, which $= 1$ for $B' << 1$, and $\simeq (1/12) \times (315/19)^2 \times 3 \times (1/6B'^3)^2 \simeq 1.9 B'^{-6}$ for $B' >> 1$ (Harding et al. 1997). Generally, we can assume $\mathcal{F}(B') \simeq \mathcal{A} B'^{-\beta}$ in a certain B' regime, where $\mathcal{A}$ and β are constants in that regime. Again, for $\theta_0 = 0$, one can solve for the averaged photon splitting attenuation length, λ_{sp}, through the definition $\int_0^{\lambda_{sp}(\epsilon)} T_{sp}(\epsilon, s) ds = 1$, where s is the trajectory length of the photon propagation. Neglecting B' declination with height which is not important for $\epsilon \gg 1$, this gives $\lambda_{sp}(\epsilon) \simeq 1.5 \mathcal{A}^{-1/7} B'^{-(6-\beta)/7} \epsilon^{-5/7} \rho^{6/7}$. For a pure dipolar geometry, this is

$$\lambda_{sp}^{B'\sim 1}(\epsilon) \simeq 1.0 \times 10^7 \text{ cm } \epsilon^{-5/7} B'^{-15/28} P^{3/7} r_{e,6}^{3/7} \xi^{-6/7} \quad (3)$$

for $B' \gtrsim 1$ (relevant to HBPs), where $\beta \simeq 9/4$ has been adopted based on an approximate fit to the numerical calculations of Baring & Harding (2001). When $B' \gg 1$ which is more relevant to AXPs/SGRs, $\mathcal{A} = 1.9$, $\beta = 6$, and the B'-dependence disappears, which gives

$$\lambda_{sp}^{B'\gg 1}(\epsilon) \simeq 0.9 \times 10^7 \text{ cm } \epsilon^{-5/7} P^{3/7} r_{e,6}^{3/7} \xi^{-6/7}. \quad (4)$$

For $\theta_0 \neq 0$, the above approximations are still valid far below the in-situ one-photon pair production threshold.

Two-photon pair production, i.e., $\gamma\gamma \to e^+e^-$, is a second-order process and can execute even without the presence of a magnetic field. Its relative importance with respect to the one photon pair production within the context of a neutron star has been studied previously (e.g. Burns & Harding 1984; Zhang & Qiao 1998). In the polar cap context, the interaction is between the two photon species, i.e., a soft X-ray component due to the thermal emission from the surface, and a hard γ-ray component produced by the relativistic primary electrons via curvature radiation or inverse Compton scattering. The importance of this process generally requires a hot polar cap (Zhang & Qiao 1998), which seems not achievable in normal pulsars (e.g. Harding & Muslimov 2001). However, AXPs/SGRs have luminous quiescent X-ray emission, and their spectra usually include a hot blackbody component (e.g. $kT \sim 0.43$ keV$\sim 5 \times 10^6$ K for 1E 2259+586) with a much larger inferred emission area (the radius ~ 3 km for 1E 2259+586, e.g. Corbet et al. 1995; Rho & Petre 1997). Both the high temperature and the large emission area make two-photon pair production a potentially important process to explore. The threshold condition for magnetic two-photon pair production is (Daugherty & Bussard 1980; Kozlenkov & Mitrofanov 1986)

$$(\epsilon_1 \sin\theta_1 + \epsilon_2 \sin\theta_2)^2 + 2\epsilon_1\epsilon_2[1 - \cos(\theta_1 - \theta_2)] \geq 4, \quad (5)$$

where ϵ_1 and ϵ_2 are the soft and hard photon energies, and θ_1 and θ_2 are the angles of their directions of momenta with respect to the magnetic field line, respectively. In the present problem, we have $\epsilon_2 \gg \epsilon_1$ ($\epsilon_2/\epsilon_1 \sim 10^6$ at the threshold). Given $\theta_2 = \gamma_p^{-1}$, the first term in (5) is negligible as long as $\gamma_p \gg 10^3$, and the threshold condition is reduced to that of non-magnetic two-photon pair production, i.e., $\epsilon_1\epsilon_2(1 - \cos\theta_1) \geq 2$ (e.g. Gould & Schréder 1967). For a semi-isotropic blackbody emission from surface, we further have $\theta_1 \lesssim 90^{\rm o}$. The typical soft photon energy is $\epsilon_1 \simeq \Theta = kT/m_e c^2 = 8.4 \times 10^{-4} (T_6/5)$. Hard photons with $\epsilon_2 \geq \epsilon_{th,2p} = \Theta^{-1} \simeq 1.2 \times 10^3 (T_6/5)^{-1}$ can in principle pair produce in the soft photon sea. These photons are readily generated by primary particles via inverse Compton off the thermal photons and the photon splitting cascade (§3).

What is more essential is to estimate the γ-ray attenuation length of this process. Though a fully magnetic two-photon pair production treatment (e.g. Kozlenkov & Mitrofanov 1986) is desireble, no directly usable formula for the present problem (two photon species) is available

at this time. We therefore treat the process using the non-magnetic cross section, keeping in mind that the strong field effect may influence some of the conclusions considerably. The non-magnetic polarization-averaged γ-ray attenuation coefficient with energy ϵ in a thermal photon sea characterized by $\Theta = kT/m_e c^2$ can be written as (Gould & Schréder 1967; Zhang & Qiao 1998)

$$T_{2p}(\epsilon, s) = \frac{\alpha^2}{\pi\Lambda}\Theta^3 F(\epsilon, s) \simeq 2.1 \times 10^{-6} T_6^3 F(\epsilon, s), \qquad (6)$$

where s is the trajectory length of the photon assuming the photon being ejected at the surface. We may write the reduction factor $F(\epsilon, s) = g(s)f(\epsilon)$, where $g(s) \simeq (0.270 - 0.507\mu_c + 0.237\mu_c^2)$ takes care of the non-isotropy of the soft photons with respect to the height (Zhang & Qiao 1998), and $\mu_c = \cos\theta_c = [1 - R^2/(R+s)^2]^{1/2}$ is the maximum cosine of the impact angle between the two photons, which is applicable when the hot surface area is much larger than the polar cap as is the case for AXPs/SGRs. For $s \ll R$, and noticing the semi-isotropic surface emission, we have $\mu_c \sim 0$ and $g(s) \sim 0.27$. The function $f(\epsilon)$ reaches the maximum ~ 1 when $\epsilon \sim \epsilon_{th,2p} \sim \Theta^{-1}$, and declines as ϵ^{-1} when $\epsilon \gg \epsilon_{th,2p}$ in the form of $f(\epsilon) \sim (\pi^2/3)\Theta^{-1}\epsilon^{-1}\ln(0.117\Theta\epsilon)$ (Gould & Schréder 1967). Near $\epsilon_{th,2p}$, the attentuation length for two photon production is then

$$\lambda_{2p}(\epsilon_{th,2p}) \sim [T_{2p}(\epsilon_{th,2p})]^{-1} \simeq 1.4 \times 10^4 \text{ cm } (T_6/5)^{-3}. \quad (7)$$

At the same γ-ray energy, i.e., $\epsilon_{th,2p} \sim 1.2 \times 10^3$ ($T_6 \sim 5$ adopted), we have $\lambda_{sp}(\epsilon_{th,2p}) \sim 1.5 \times 10^5$ cm $P_1^{3/7}$ (eq.[4]), and $\lambda_{1p}(\epsilon_{th,2p}) \sim 4.9 \times 10^5$ cm $P_1^{1/2}$ (eq.[1]). We therefore have

$$\lambda_{2p}(\epsilon_{th,2p}) < \lambda_{sp}(\epsilon_{th,2p}) < \lambda_{1p}(\epsilon_{th,2p}) \qquad (8)$$

for a typical AXP/SGR environment. This means that even if photon splitting can suppress one-photon pair production, it cannot suppress two-photon pair production, at least at the two-photon threshold. Several comments ought to be made. First, again strong fields may modify the conclusion greatly. Though more detailed investigations are required to tell these modifications, we may try to guess some of these effects. Generally, strong fields will suppress the two-photon cross section, but there are "resonances" at which the cross sections are much enhanced, due to discreted Landau energy levels of the created pairs (Kozlenkov & Mitrofanov 1986). Given the broad spectral distributions of both the hard photons and the soft photons, there may always be some preferred two-photon attenuations to occur with even shorter attenuation lengths than the one estimated in (7), so that (8) may be not changed. Second, equation (8) is applicable when $\theta_0 = 0$, or, when $\epsilon \ll \epsilon_{th,1p}$ if $\theta_0 \neq 0$. Third, in all the above treatments, polarization-averaged cross sections have been adopted, while the threshold conditions for both one-photon and two-photon pair production are polarization-dependent. Nonetheless, usually the primary γ-rays are dominated by the $\perp$ mode, and polarization-dependent treatments will not change the above discussions qualitatively. Finally, two photon pair production attenuation length is sensitive to the surface temperature ($\propto T^{-3}$). The condition to ignore the two-photon process is $\lambda_{2p}(\epsilon_{th,2p}) > \max[\lambda_{sp}(\epsilon_{th,2p}), \lambda_{1p}(\epsilon_{th,2p})]$, or

$$T_6 < \max\,(3.4P^{-3/26}, 2.7P^{-1/8}). \qquad (9)$$

A non-zero θ_0, or a smaller hot area (e.g. polar cap in normal pulsars) will make the constraint less stringent. The condition (9) usually holds for HBPs, but not for AXPs/SGRs.

3. RADIO QUIESCENCE OF AXPS/SGRS AND DEATHLINE FOR HBPS

Pair production in a pulsar magnetosphere is believed to be an essential, though perhaps not sufficient, condition for coherent radio emission. Radio quiescence of the AXPs/SGRs has been attributed by Baring & Harding (1998; 2001) to the suppression of pair production by photon splitting, under the hypothesis that photons with both polarization modes split. However, as discussed above, two-photon process is another pair formation mechanism, and it may still produce pairs even if the photon splitting hypothesis holds, at least for photons near the two-photon threshold with a zero or negligible impact angle with the field line. The question is whether a copious number of such photons exist in the magnetar inner magnetosphere.

The typical energy of the primary particles in a magnetar environment is not well-studied. Nonetheless, copious pairs may be not generated initially, so it is reasonable to expect γ_p not too much below $\gamma_{p,m} \sim 10^7$. Since magnetars are slow rotators, characteristic curvature radiation energy, $\epsilon_{cr} = (3/2)(\gamma_p^3\hbar c/\rho m_e c^2) \sim 200P_1^{-1/2}\gamma_{p,7}^3$, is below $\epsilon_{th,2p}$, even for the maximum electron energy. The main source of the hard photons above 1 GeV is inverse Compton scattering (Gonthier et al. 2000). Resonant scattering off the thermal peak generally requires $\gamma_p \sim B'/\Theta \sim 6 \times 10^4 B_1'$, a condition easily satisfied during the acceleration phase of the primary particles. The characteristic photon energy is $\epsilon_{res} \sim \gamma_p B' \sim 6 \times 10^5 (B_1')^2$, which is well above $\epsilon_{th,2p}$ and around $\epsilon_{th,1p}$. These γ-rays may otherwise pair produce via one-photon process, but under the Baring & Harding photon splitting hypothesis, they will split to lower energy photons through a splitting cascade. The daughter photon energies approach $\epsilon_{th,2p}$ after several generations where the two-photon attenuation length is the minimum. Assuming that the daughter photons mainly follows the direction of the parent photon, The θ_0 effect at this time is not important since $\epsilon_{th,2p} \ll \epsilon_{th,1p}$, and according to (8), we expect that at least some pairs will produce via the two-photon process. If these pairs are not copious enough to screen the parallel electric field, electrons keep accelerating to reach higher energies, e.g., $\gamma_p \sim 10^6$. These electrons will also inverse Compton scatter the thermal photons in the Klein-Nishina regime with typical photon energy $\epsilon_{KN} \sim 10^6\gamma_{p,6}$ and the initial ejection angle $\gamma_0 \sim 10^{-6}\gamma_{p.6}^{-1}$. These photons may also undergo photon splitting cascade, and pair produce near $\epsilon_{th,2p}$. This goes on until primary electron energy saturates.

At present, there is no firm detection of pulsed radio emission from the known AXPs and SGRs. This is a natural expectation if these objects are accretors (e.g. Chaterjee, Hernquist & Narayan 2000). However, if they are indeed magnetars, the non-detection of emission in the "conventional" radio band ought be re-investigated due to the

above reason. It could be possible that the hot environments may destroy some fragile conditions (e.g., bunching condition or maser condition) that are necessary to generate coherent radio emission. Other suggestions include the influence of the bursting activities (Thompson 2000). Here we propose that even if photon splitting can completely suppress one-photon pair production, radio emission from AXPs/SGRs may be not prohibited. The emission, if at all, should be mainly emitted in longer wavebands. For example, the characteristic curvature radiation frequency of the pairs is $\nu_{cr} = (3/4\pi)(c/\rho)\gamma_\pm^3 \propto P^{-1/2}\gamma_\pm^3$, where $\gamma_\pm$ is the Lorentz factor of the pairs. In AXPs/SGRs, both long periods and small $\gamma_\pm$'s tend to lower the typical radio emission frequency. The latter is mainly due to that pairs are more likely to generate near $\epsilon_{th,2p}$. We thus expect that the typical pair energy in AXPs/SGRs might be less than that in normal pulsars generated via one-photon pair production, and that AXPs/SGRs may be radio loud in lower frequency bands. There are reports that SGR 1900+14 (Shitov 1999) and the AXP 1E 2259+586 (Malofeev & Malov 2001) have been detected with low-frequency pulsed emission at 111 MHz. If these claims are confirmed, they are consistent with the theoretical expectation presented here. Also Gaensler et al. (2001) recently pointed out that non-detection of radio emission in AXPs/SGRs does not necessarily mean that they are intrinsically radio quiet due to the inadequate searching sensitivity and the beaming effect.

For HBPs, (9) generally holds, and one can safely neglect two-photon pair production. The photon-splitting-dominant condition is then $\lambda_{sp}(\epsilon) < \lambda_{1p}(\epsilon)$, which translates to (with the use of eqs.[1] and [3]) $B'^{15/28}\epsilon^{-2/7}P^{1/14}r_{e,6}^{1/14}\xi^{-1/7} > 0.054$ with a negative ϵ-dependence. Baring & Harding (1998; 2001) defined a "photon splitting deathline" using the criterion that the escape energy of both one-photon pair production and photon splitting is equal. More generally, one may derive the typical photon energy ϵ from a gap as well as its $P-$, B_p-dependences by choosing a gap boundary condition and a γ-ray emission mechanism (e.g. Zhang et al. 2000) to define the "photon splitting dominant line" for a particular model. These lines generally tilt up in the short period regime relative to the Baring & Harding (1998) deathline, and allow some short-period HBPs, e.g., PSR J1119-6127 (Camilo et al. 2000), to be below the line. This is understandable: Faster pulsars tend to have larger acceleration potentials and hence, produce more energetic photons than the slower pulsars, and for higher energy photons, even higher magnetic fields are required for photon splitting to dominate. For example, for a resonant inverse Compton-controlled vacuum gap (which is more possible in the high B regime), the typical photon energy may be expressed as $\epsilon_c(\mathrm{ICS-VG}) \simeq 5.5 \times 10^4 P^{1/14} B' \xi^{-3/7}$, and the photon splitting dominant line is (Zhang & Harding 2001)

$$B_p \geq 1.0 \times 10^{14}\mathrm{G}(P/1\mathrm{s})^{-10/49}\xi^{4/49}, \tag{10}$$

or $\dot{P} \geq 2.44 \times 10^{-12}(P/1\mathrm{s})^{-69/49}\xi^{8/49}$ by adopting $B_p = 6.4 \times 10^{19}\mathrm{G}\sqrt{P\dot{P}}$. This is also the deathline for the anti-parallel rotators in which vacuum-type inner gaps are expected. For parallel rotators, a similar line for the space-charge-limited-flow type inner gap may be obtained after detailed numerical calculations (Harding et al. 2001, in preparation). This is a line to define whether delayed pair formation is necessary, rather than a deathline, which is then defined according to the binding condition at the surface (Zhang & Harding 2000).

4. SUMMARY & DISCUSSION

We have shown that if AXPs/SGRs are indeed magnetars, even if photon splitting could completely suppress one-photon pair production, γ-rays in the magnetar magnetosphere may still generate electron-positron pairs via two-photon pair production, mainly because the AXP/SGR environments are very hot. Non-detection of radio emission from AXPs/SGRs may be because the low energy pairs generate radio emission with too low a frequency to be observable in the bands above several hundred MHz. Searching for low frequency emission from these objects is of great interest, and if detected, the low frequency emission will rule out the accretion models. This conclusion does not expel the photon splitting hypothesis which could be tested in HBPs. For example, if the recently discovered 424 ms radio quiet pulsar (Zavlin et al. 2000) turns out a HBP, it may lend support to the photon splitting hypothesis of Baring & Harding (1998), and the geometric proposal of Zhang & Harding (2000).

Several caveats ought to be noted. Only a very crude treatment, especially for the two-photon pair production, is performed in this letter. More detailed cascade simulations by including all the three relevant QED processes, i.e., one-photon, two-photon pair production, and photon splitting, with a full "magnetic" treatment are needed to provide a clearer understanding of the whole phenomenon. As a first step, a more user-friendly treatment of the two-species magnetic two-photon pair production is called for. Dipolar magnetic fields have been assumed throughout. In magnetars, multi-pole components may exist, and this will enhance one-photon production and may weaken the proposal discussed here. Finally, two photon pair production may also be important in another type of pulsars, i.e., the millisecond pulsars, where the one photon process is less important due to the weak dipolar fields involved.

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